Mem. Natl Inst. Polar Res., Spec. Issue, **50**, 85–107, 1994

NOTES ON LATE-GLACIAL RETREAT OF THE ANTARCTIC ICE SHEET AND HOLOCENE ENVIRONMENTAL CHANGES ALONG THE VICTORIA LAND COAST

Carlo BARONI

Dipartimento di Scienze della Terra–Università degli Studi di Pisa, and C.N.R.– Centro di Studio per la Geologia Strutturale e Dinamica dell'Appennino, via S. Maria, 53. I-56126 PISA, Italy

Abstract: Distinct recessional phases with minor readvances of the outlet glaciers in Victoria Land are documented during Late Glacial times when the Antarctic Ice Sheet and its fringing ice shelves receded from the continental shelf in the Ross Sea embayment. Abandoned penguin rookeries supply data both on the history of the glacial retreat that followed the LGM and environmental changes during the Holocene. These were found along the Victoria Land coast and supplied more than seventy ^{14}C dates as old as 13070 ± 405 ^{14}C yr B.P. (GX-18483). Marine ingression and the glacio-isostatic uplift of the coastal areas that led to the formation of Holocene raised beaches accompanied deglaciation. Several ^{14}C dates obtained from shells collected in raised marine sediments and from fossil rookeries resting on the raised beaches constrain a relative sea-level curve for the central part of Victoria Land. Penguins are sensitive to changes in Antarctic climate and to the environmental parameters that determine their presence and distribution that seem to have changed many times during the Holocene in the Ross Sea. Holocene glacier variations in the Terra Nova Bay area are documented for outlet and local glaciers as well as for ice shelves.

Key words: glacial history, environmental change, raised beaches, Victoria Land, Antarctica.

1. Introduction

Antarctic coastal areas are almost entirely ice-covered. Ice cliffs originated by the huge continental ice sheet that feeds ice shelves and tongues delimit most of the coastline. Rocky coasts are located in small areas scattered all around the continent. Due to their distribution, they are relevant for studies on Antarctic glacial history, with particular attention to the Last Glacial Maximum (LGM, oxygen isotope Stage 2) and to the following retreat phases. As suggested by the first observation made at the beginning of this century, during LGM, Antarctica was covered by an expanded ice sheet advancing onto the continental shelf (SCOTT, 1905) and coastal areas were buried by hundred of meters of ice. They became ice-free only after the retreat of the late Wisconsin ice sheet. Records of late glacial withdrawal phases, and of Holocene glacier fluctuations are documented by landforms and deposits in those ice-free areas.

Holocene raised beaches and marine terraces that are to be found on the low rocky coasts document the marine ingression and the isostatic rebound of the Antarctic coastal belt.

The characterisation of raised beaches is the first necessary step to investigate the isostatic rebound of the lithosphere unloaded after the retreat of the expanded late Pleistocene Antarctic ice sheet. Furthermore, considering that variation of the ice sheets is a prominent cause of sea-level changes, relative curves from different coastal areas

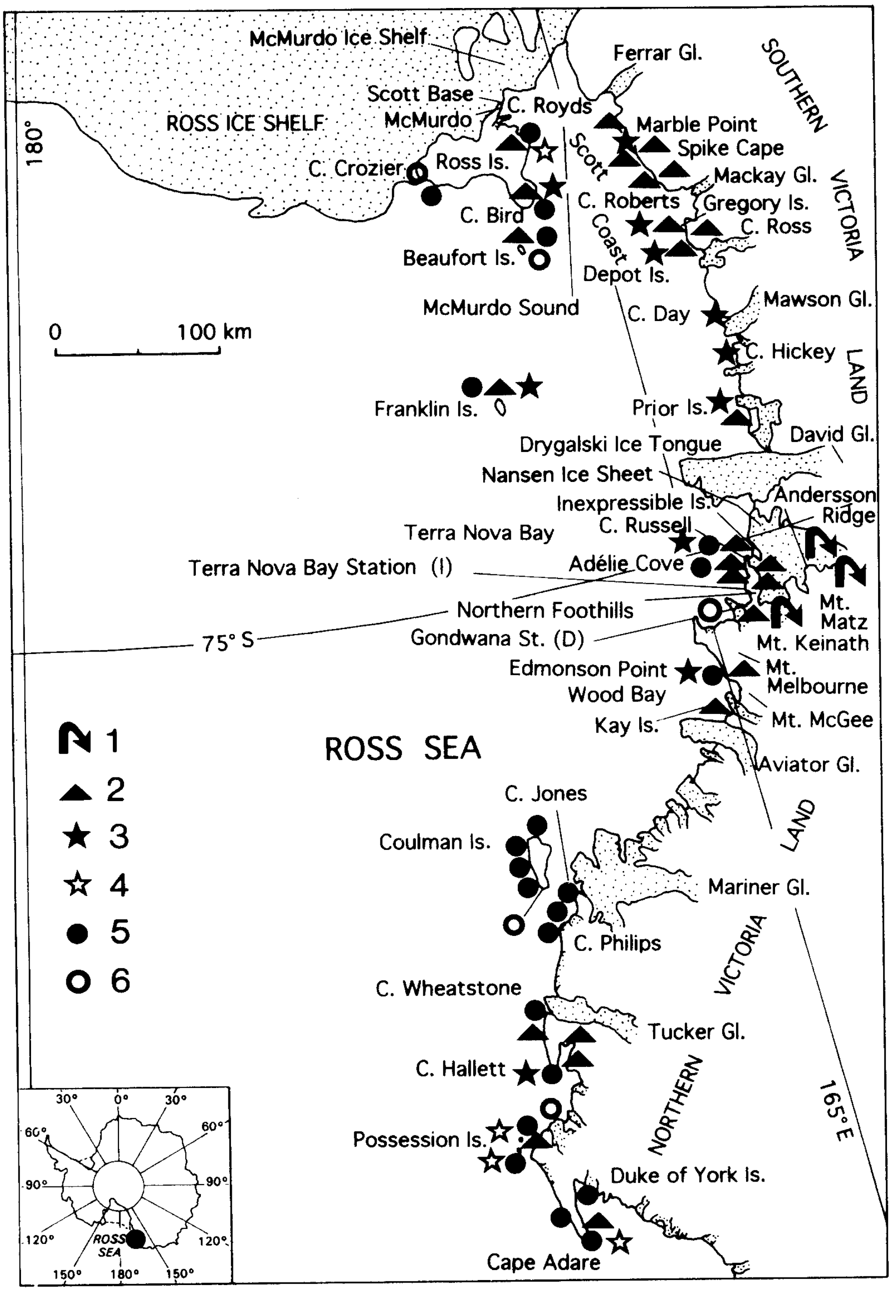


Fig. 1. Distribution of late glacial and Holocene relevant features along the Victoria Land coast. 1) Recessional moraine (late glacial). 2) Holocene emerged features (raised beaches, marine platform, marine pavement). 3) Abandoned Adélie penguin rookery (radiocarbon dated; see Appendix data). 4) Ornithogenic soil not yet dated. 5) Adélie penguin rookery. 6) Emperor penguin rookery.

supply information on the Antarctic ice sheet contribution to world sea-level changes during late glacial and Holocene times. Finally, the behaviour of the Antarctic ice sheet in response to past climatic variations is the key to understand its response to present or future possible environmental modifications.

Since 1986, I have studied the glacial geology and geomorphology of Victoria Land coastal areas (Fig. 1) in the framework of the Italian Antarctic Research Program (BARONI, 1989, 1990; BARONI and OROMBELLI, 1989, 1991, 1994; OROMBELLI *et al.*, 1991). Research was carried out to get new information on the glacial history of the coastal areas. The Terra Nova Bay territory has been particularly focused (due to the establishment of the Italian base in 1986) but work has been carried out on both north and south of Victoria Land coastal belt. Here I summarise the main results we obtained so far and discuss their relevance for the late glacial to Holocene history of Victoria Land (Fig. 1).

2. Materials, Methods and Previous Work

Various glacial drifts, glacial geomorphological features and emerged marine landforms in coastal areas were mapped from aerial photographs and directly surveyed; Holocene moraines and glacial deposits were differentiated on the basis of weathering degree and lichen cover (OROMBELLI, 1986; BARONI, 1989; BARONI and OROMBELLI, 1989; OROMBELLI *et al.*, 1991).

Holocene raised marine features that post-date late Pleistocene glacial deposits and erosional surfaces are the most prominent features in several ice-free coastal areas of Victoria Land (Fig. 1), from Cape Adare to Ross Island (DAVID and PRIESTLEY, 1914; TAYLOR, 1922; PRIESTLEY, 1923; NICHOLS, 1966, 1968; CAMPBELL and CLARIDGE, 1966a;

Fig. 2. Sequence of Holocene raised beaches at Spike Cape (southern Victoria Land). Emerged marine features are common features on the ice-free coasal areas of Victoria Land, from Cape Adare to Ross Island (Dec. 1990).

CLARIDGE and CAMPBELL, 1966; DENTON *et al.*, 1975; STUIVER *et al.*, 1981; GREGORY *et al.*, 1984; MABIN, 1986b; WHITEHOUSE *et al.*, 1988, 1989; BARONI and OROMBELLI, 1989, 1991; KIRK, 1991; COLHOUN *et al.*, 1992). They are easily identifiable features, well developed but sporadically distributed in northern Victoria Land. They are more common at Terra Nova Bay and in southern Victoria Land, especially along the Scott Coast (Fig. 2). Cuspate forelands and spits with several individual beach ridges are present at Cape Adare, Cape Hallet, Edmonson Point and on Possession, Franklin and Beaufort Islands. Well-developed sequences of pebbly to bouldery berms are found in several other localities. Deltaic deposits, marine-boulder pavements and emerged wave-cut platforms are less common but well developed in some places. Patches of sandy to silty littoral sediments are locally present between the berm ridges and in the most protected coves. They are very rare but are the most useful deposits in which it is possible to find marine shells.

Topographic profiles were levelled across the sequence of raised beaches and other marine landforms (BARONI and OROMBELLI, 1989, 1991), up to the marine limit that, on the rocky coasts and particularly on the headlands, is defined by a sharp boundary between a wave-washed surface and irregular erratic fields. The altitude of raised beaches was referred to mean sea level measured in the Terra Nova Bay area with a maximum estimated error of ± 30 cm.

To obtain material suitable for ^{14}C dates, and therefore to date the emerged beaches in order to reconstruct a relative sea-level curve, we sought for two distinct groups of organic matter (see Appendix 8): 1) marine organisms in littoral sediments and 2) guano from ornithogenic soils resting on Holocene raised beaches. Other ^{14}C dates were obtained from shells collected on the Cape Russell peninsula (at Evans Cove) and at

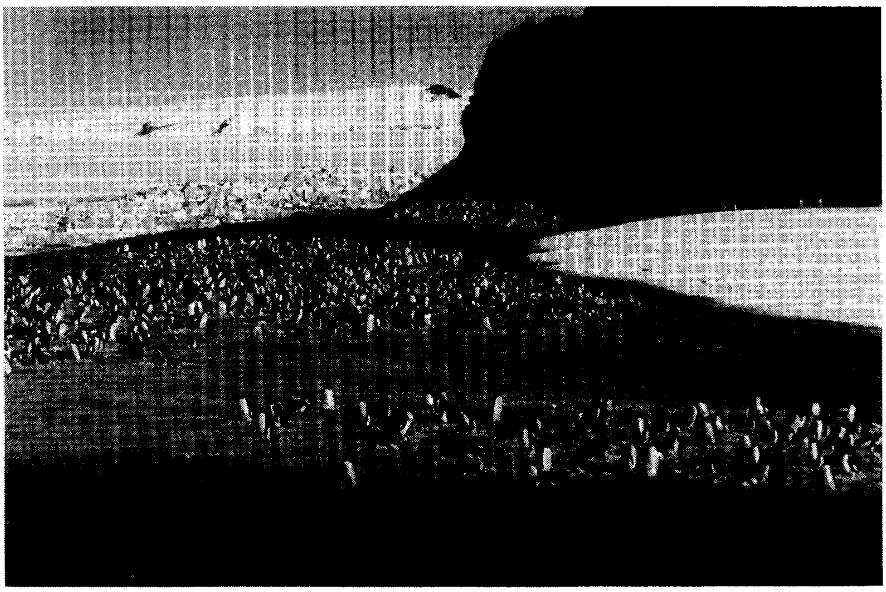


Fig. 3. The Adélie penguin rookery at Edmonson Point (Wood Bay) developed on elevated beach deposits (3 m a.s.l.; Jan. 1988). Accumulation of guano, feathers, egg fragments and bird remains in penguin rookeries produce ornithogenic soils. Note the soil developing in the areas settled by penguins that marks a sharp boundary (foreground) with the surrounding beach sediments (made by dark volcanic rocks).

Edmonson Point, Wood Bay (BARONI and OROMBELLI, 1991, 1994b; BARONI *et al.*, 1991).

New information has come from studies on the distribution of presently occupied and abandoned Adélie penguin (*Pygoscelis adeliae*) rookeries. The presence of guano on the Antarctic coasts has been recognised since the historical expeditions of the last century. The first Antarctic insects were collected in deposits of guano by ARÇTOWSKY (1901), geologist of the *de Gerlache Expedition*. Organic soils from penguin rookeries were termed ornithogenic soils by SYROECHKOVSKY (1959) and were later described in Victoria Land by HARROMGTOM (1960), TEDROW and UGOLINI (1966), CAMPBELL and CLARIDGE (1966b, 1987), SPELLERBERG (1970), UGOLINI (1972), SPEIR and COWLING (1984), HEINE and SPEIR (1989). Accumulation of droppings, feathers, egg fragments and bird remains in penguin rookeries produce ornithogenic soils (Fig. 3). Their thickness ranges from some centimeters to some decimeters and the areal diffusion is locally extensive depending on the size of the rookery and age of establishment. According to HARRINGTON (1960) and UGOLINI (1972), the thicker the soil, the older the rookery. Ornithogenic soils are found in active rookeries and at their margins, testifying to the presence of abandoned penguin nesting sites. Furthermore, soils are present in areas where penguins do not nest at present documenting the existence of fossil rookeries (Fig. 1). The first abandoned penguin rookeries were discovered during the 1910–13 Scott "TERRA NOVA" Expedition by DEBENHAM (1923) who pointed out the presence of two "old penguin rookeries" near Cape Royds (Ross Island). SPELLERBERG (1970) and STONEHOUSE (1970) later studied the same locality.

Accumulations of well-sorted pebbles that penguins selected to build their nests (Fig. 4) characterise fossil rookeries. After the abandonment of the rookery, pebbles are concentrated by deflation at the surface and protect the lower guano, thus giving

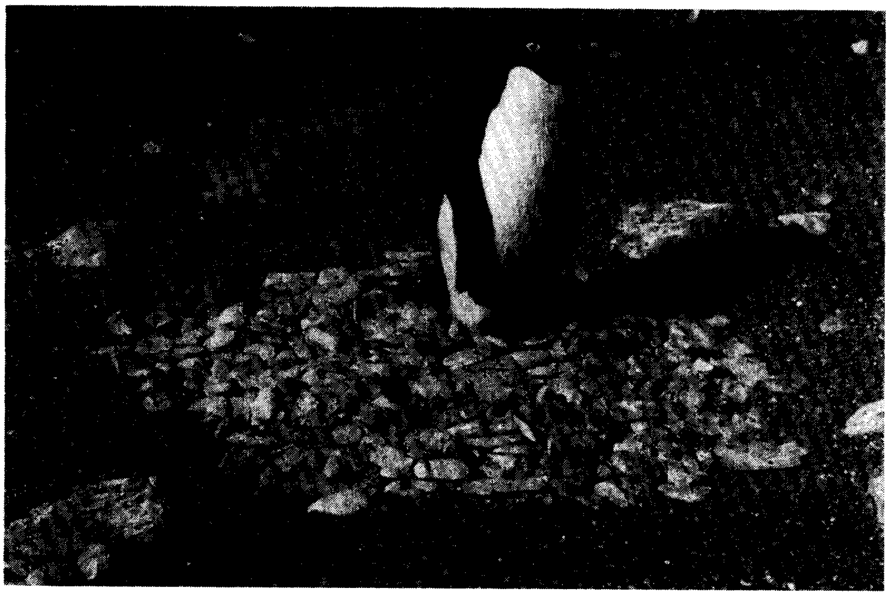


Fig. 4. Adélie penguin nest resting on beach sand at Edmonson Point (Wood Bay, Jan. 1988). Concentration of pebbles selected by penguins to build their nests characterizes abandoned sites in present-day and fossil rookeries. These pebbly patches hide ornithogenic soils, that provide datable organic remains such as bones, feathers, fragments of eggs, and guano.

Fig. 5. Cape Ross. Patches of pebbles (foreground) selected by penguins to build their nests rest on Holocene bouldery beach deposits and cover ornithogenic soil of fossil rookery (Dec. 1990).

rise to benches of pebbles extending over several dozen square meters (Fig. 5). A diffuse lichen cover grows on pebbles of the oldest abandoned nests.

Fossil rookeries supply data on the history of glacial retreat that followed the LGM and on the environmental history of the Holocene. They also provide the opportunity to obtain dozens of ^{14}C dates from penguin guano and remains collected in abandoned penguin nesting sites (BARONI and OROMBELLI, 1991, 1994). Not all the fossil rookeries rest on beach deposits; some of them develop above the marine limit and are not useful to reconstruct a relative sea-level curve. In fact, to be able to reach this target, it is necessary to date penguin remains resting on coastal deposits that supply minimum ages of individual raised beaches. These dates, together with those from shells collected *in situ* in marine sediments, constrain relative sea-level curves.

Winnowed marine specimens and seal skeletons on the surface of raised beaches supplied additional ^{14}C dates (OROMBELLI, 1988; BARONI, 1989; BARONI *et al.*, 1991). All these dates are minimum ages for the beach on which they rest, but they are useless considering their young age regardless of the altitude at which they were collected.

An independent method of investigating the age of raised beaches is by means of lichen growth curves of the genus *Buellia.* As it is well known, lichenometry is an "incremental" dating method based on the assumption that there is a direct relationship between lichen age and size: the older the thallus the bigger its diameter. Measurements of circular and single individual thalli are required and the minimum diameter of the largest inscribed circle for each thallus must be determined. According to OROMBELLI and PORTER (1983), only the largest recorded value of any berm was used, "on the assumption that this individual most closely reflected the time when the substrate first became available for colonisation". The largest diameters were generally obtained on more than one subject and several other measurements were within 2 mm of the largest thalli.

3. Results

On the coast of the Terra Nova Bay area, the glacial deposits related to the LGM, *Terra Nova drift*, occur up to the maximum altitude of about 400 m above the present sea level. *Terra Nova drift* is a thin and discontinuous matrix-supported diamict that is widely replaced by an erratic field. In some places it consists of massive matrix- supported diamict with a silty sandy matrix of marine origin that contains shells of several marine organisms. A.M.S. and conventional ^{14}C dates supplied by these fossils indicate that the age of this deposits is between about 25 and 7.5 kyr B.P. the glacial retreat that followed the LGM was entirely accomplished (OROMBELLI *et al.*, 1991). This retreat did not occur in a single phase but was more complex. Between the late Wisconsin trimline and the present glacier surface there are moraines located at different levels that bear witness to distinct recessional phases of the outlet glaciers that directly drain the East Antarctic ice sheet. In particular, they are recorded near Andersson Ridge, at Mt. Matz and Mt. Keinath (BARONI and OROMBELLI, 1989; OROMBELLI *et al.*, 1991).

Holocene raised beaches developed in coastal areas after deglaciation. They are sporadically situated all along the Victoria Land coast at different altitudes (NICHOLS, 1968; STUIVER *et al.*, 1981; GREGORY *et al.*, 1984; BARONI, unpublished data). From North to South, the marine limit rises from 5–6 m at Cape Adare–Cape Hallett, to 15 m in Wood Bay and to 31 m in Terra Nova Bay. The highest recorded marine limit has been noted at Cape Ross, where it reaches 34 m. Further South, the limit decreases to 20 m a.s.l. along the Scott Coast, to become progressively lower at McMurdo Sound, where no traces of Holocene raised beaches have ever been found.

New information regarding the deglaciation history comes from penguin remains and abandoned penguin nesting sites found along the Victoria Land coast (Fig. 6). More than 80 ^{14}C dates obtained from penguin remains spanning from 13070 ± 405 ^{14}C yr B.P. (GX-18483) to the present come from the Ross Sea sector (Appendix data). HARRINGTON and MCGELLAR (1958), HARRINGTON (1960), SPELLERBERG (1970) and STONEHOUSE (1970) obtained a first group of 7 dates of recent penguin bones and remains. A group of 10 ages of penguin remains date to the first half of the 1980's and gave information of interest for Holocene history (STUIVER *et al.*, 1981; SPEIR and COWLING, 1984; WHITEHOUSE *et al.*, 1989). A consistent group of more than 60 dates was obtained in the second part of the 1980's and refers to guano and other remains from ornithogenic soils (OROMBELLI, 1988; BARONI, 1989; BARONI and OROMBELLI, 1989, 1991, 1994a; HEINE and SPEIR, 1989).

Seven dates from Emperor and Adélie penguins come from remains of known age collected in the vicinity of sites settled during historical expeditions (STUIVER *et al.*, 1981; MABIN, 1985, 1986a; WHITEHOUSE *et al.*, 1989; BARONI and OROMBELLI, 1991). These dates, together with those from other remains of known age, are necessary to calibrate older dates contained in the geological record (OMOTO, 1983; STUIVER *et al.*, 1986; STUIVER and BRAZIUNAS, 1993; STUIVER and REIMER, 1993). In fact, because the Antarctic oceanic waters are depleted in ^{14}C, the ages supplied by shells and other organisms (*e.g.* penguins) that lived or fed in the sea supply dates more than one thousand years older than their age. The date from materials of known age is necessary

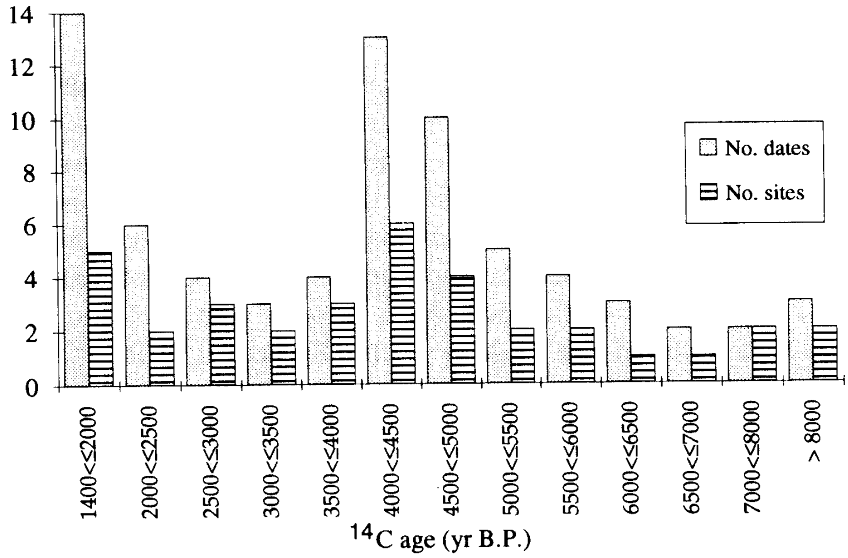


Fig. 6. Number of conventional ^{14}C dates and penguin rookeries versus time intervals. The chart is based on 73 dates from Victoria Land. Ages from samples of known age or younger than 600 conventional years B.P. have not been taken into account. The history of penguin colonization of Victoria Land shows that the Scott Coast has been particularly sensitive to environmental factors that limit the presence of penguins. Of these factors, probably the most important, is the variation of the extent and the persistence of the fast ice that is mainly controlled by the summer temperature.

to eliminate or, at least to reduce to the minimum value, this "reservoir effect".

Finally, abandoned snow petrels' nesting sites furnished an additional 15 dates ranging from 9080±100 ^{14}C yr B.P. (TO-2659) to 1360±60 ^{14}C yr B.P. (TO-2671) (BARONI, unpublished data). Although penguins provided the most concrete data, the snow petrels can also contribute to our knowledge regarding the environmental conditions (*e.g.* access to the sea, distribution of ice free areas, glacier elevations, etc.) and the presence of life in the coastal area (*e.g.* availability of food) of Victoria Land since the early Holocene.

The oldest fossil rookery yet found is at Cape Hickey (N of Mawson Glacier along the Scott Coast; Fig. 1). It lies above the marine limit (about 40 m a.s.l.) and supplied the dates 11035±360 (GX-16925) and 13070±405 ^{14}C yr B.P. (GX-18483). This abandoned rookery testifies about favourable conditions for the presence of penguins at that time but the Adélie penguins' diffusion on the Victoria Land coast was only confirmed from about 7 kyr B.P. Some colonies have been occupied ever since while other sites were used for certain periods of time and then abandoned.

Organic horizons of ornithogenic soils from abandoned penguin nesting sites resting on the raised beaches supplied many ^{14}C dates ranging from the present to about 7 kyr B.P. In some single soil pits, various samples from different horizons were dated in stratigraphic superposition (Fig. 7).

Pelecypod shells relevant for dating Holocene raised marine sediments outcrop on the Cape Russell peninsula (at Evans Cove) at the elevation of 9 to 14.5 m a.s.l. (BARONI and OROMBELLI, 1991). Radiocarbon ages of *Laternula elliptica* and *Adamussium colbecki* range from 6620±190 (GX-14825) to 7505±230 (GX-14069) ^{14}C yr B.P. At

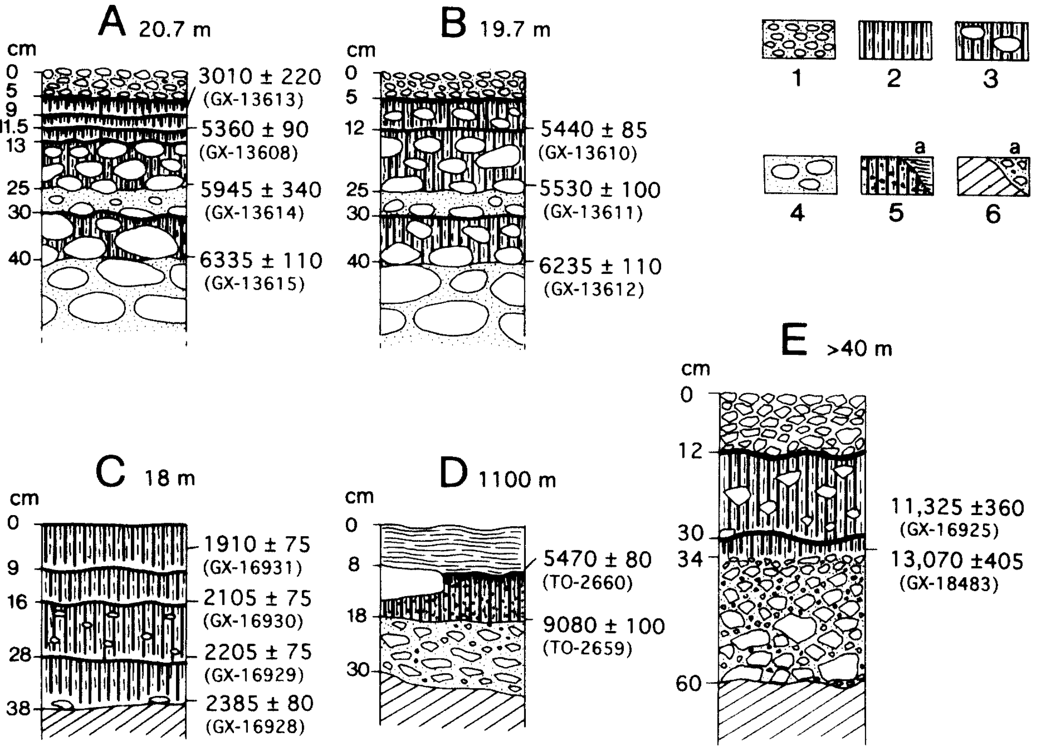


Fig. 7. Profiles of ornithogenic soils from abandoned nesting sites in Victoria Land. Conventional (GX-) or AMS (TO-) radiocarbon ages are in evidence on the right; depth in cm (on the left). See Appendix 7 for detailed description.

1) Surficial pebbly horizon accumulated by penguins. 2) Organic horizon (penguin guano). 3) Sandy gravel with penguin guano. 4) Sandy gravel and boulders. 5) Snow petrel stomach oil, guano and other organics. 5a) Snow petrel stomach oil. 6) Bedrock. 6a) Angular sandy gravel.

A, B) Inexpressible Island, southern margin of Seaview Bay; soil profiles from abandoned penguin nesting sites resting on raised beaches (20.7 and 19.7 m a.s.l., respectively). C) Prior Island (18 m a.s.l.); soil profile from abandoned penguin nesting site. D) Mt. McGee (1110 m); soil profile from a Snow Petrel abandoned nesting site. E) Cape Hickey (>40 m); profile from the oldest fossil rookery of Victoria Land.

The abandoned sites in present-day rookeries or those in no-longer occupied areas are still easily identifiable due to the presence of a thin layer of well-sorted pebbles, which had been collected by the penguins to build their nests. These pebbly patches hide relict ornithogenic soils, which are differentiated into distinct horizons of various depths. From several sites, a series of superimposed dates was obtained. These sequences document the duration and continuity of the occupation of the rookeries.

the same elevation, the samples of *Laternula elliptica* turned out to be 300–500 years younger than those of *Adamussium colbecki.*

In order to compare the dates from marine shells and from organisms that fed in the sea with other continental dates as well as with radiocarbon dates from other continents, the ^{14}C ages obtained were calibrated according to STUIVER *et al.* (1986) and STUIVER and REIMER (1993). The study and dating of the Holocene raised beaches allowed the reconstruction of a relative sea-level curve for the central part of Victoria Land (BARONI and OROMBELLI, 1991). Until now, this is the only curve of emergence available for the Antarctic coasts. The age of the highest and oldest beaches of the area

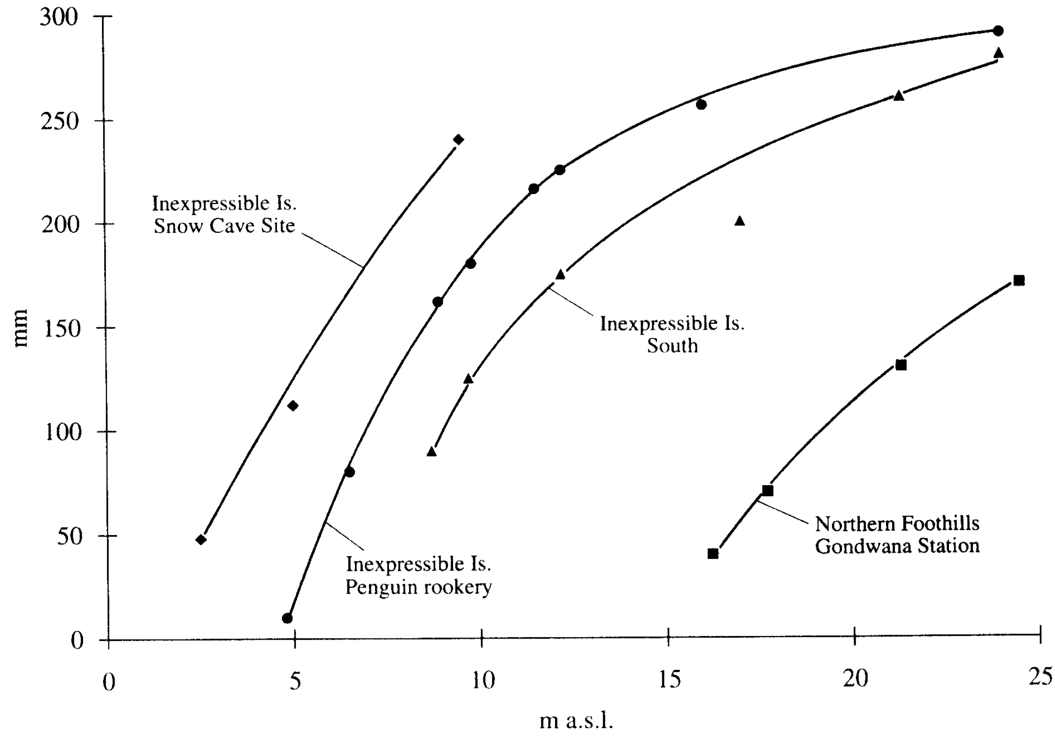


Fig. 8. Growth curves for crustose lichens of the genus Buellia as a function of the elevation above sea level (redrawn after BARONI *and* OROMBELLI*, 1989).*
Measurements were made on circular and single individual thalli. The minimum diameter of the largest inscribed circle for each thallus was determined and the largest recorded value measured for each individual berm was plotted. The lichens growth depends on local critical factors but the curves can be used to determine a relative chronology of pebbly and bouldery berms. In fact, at Terra Nova Bay the diameter of individual thalli is a function of elevation.

has been estimated to be comprised between 7 and 8 kyr B.P. The rate of emergence ranged from about 10 mm/yr following deglaciation to 2 mm/yr in the last three millennia.

The lichen growth curves obtained at Terra Nova Bay for the genus *Buellia* (Fig. 8) show that the growth rate depends on local critical factors. Nevertheless, various relative curves have been obtained from different localities. These curves can be useful to reconstruct a relative chronology of the pebbly and bouldery berms. In general, at Terra Nova Bay, the higher the beach the older the age. In fact, the first meters above the present sea-level (4 to 5 m) are without lichens and, more importantly, the size diameter of individual thalli is a function of elevation, reaching maximum values of about 290 mm at 24 m a.s.l. at Inexpressible Island. Further research in this direction is necessary.

4. Discussion

As previously reported by several authors (DREWRY, 1979; KELLOGG *et al.*, 1979; STUIVER *et al.*, 1981; DENTON *et al.*, 1989), the Ross Sea embayment was covered by an expanded Antarctic Ice Sheet with fringing ice shelves. The presence of a marine based ice sheet in the Ross Sea during the LGM has been long debated and is still a topic of discussion. Different models have been proposed on the basis of glacial geological evidence, marine geological data and glaciological considerations. Marine geophysical investigations, piston cores, sedimentological and petrographical analyses, and ^{14}C dates of foraminifera indicate that the East and West Antarctic ice sheets advanced into the Ross Sea, moving the grounding line forward up to some 100 km from the edge of the continental shelf (KARL, 1989; REID, 1989; ANDERSON *et al.*, 1991; TAVIANI *et al.*, 1993). In particular, the grounding line along the western coast of the Ross Sea was situated immediately north of Coulman Island. Floating ice shelves probably covered the remaining part of the continental shelf. The LGM extent of the pack ice was hundreds of kilometers further north from its present position (DAWSON, 1990). During the LGM ice exceeded several hundreds of meters above the present sea level over the coastal territories of Victoria Land, as documented by the distribution of late Wisconsin glacial deposits (DENTON *et al.*, 1989, 1991; OROMBELLI *et al.*, 1991). In the Dry Valleys, the LGM culminated between 23.8 kyr B.P. and 17 kyr B.P. (STUIVER *et al.*, 1981). The recession of the marine-based ice sheet and of the related ice shelf began later than 17 kyr B.P. and was completed in the early Holocene.

The glacial retreat did not occur in a single phase as documented by halts and/or weak readvances of outlet glaciers in the Terra Nova Bay area. Radiocarbon dates obtained from marine organisms associated with marine sediments, or entrapped organisms in floating ice shelves (Fig. 1) supply information about the history of the glacial retreat. The grounding line was already withdrawn to the south of Terra Nova Bay before 10824 ± 640 ^{14}C yr B.P. (KRISSEK, 1988), and to the south of Ross Island before 7750 ± 90 ^{14}C yr B.P. (QL-1443; KELLOGG *et al.*, 1990). New information comes from the abandoned penguin rookery of Cape Hickey that date back to 13–11 kyr B.P. (BARONI and OROMBELLI, 1994a). This indicates that glaciers retreated during late glacial time giving the penguins new access to the coast from then on and that the Ross Ice Shelf was to the South of Cape Hickey before 11–13 kyr B.P.

Deglaciation was accompanied by marine ingression and glacio-isostatic uplift of the coastal areas. These events led to the formation of Holocene raised beaches. The oldest berms of the Terra Nova Bay area have an estimated age of about 8 kyr B.P. (BARONI and OROMBELLI, 1991) suggesting that between at least 11–13 kyr B.P. and 7–8 kyr B.P. the coastal areas were not exposed to marine wave action. As a preliminary hypothesis we can infer that the coast of Terra Nova Bay was faced by expanded ice shelves and tongues. If this interpretation is valid it could explain the different rates of emergence documented by the different elevations of the highest raised beaches in distinct sectors of Victoria Land.

At Terra Nova Bay, the deposition of the highest and oldest beaches between (7.5 and 5 kyr B.P.) was followed by the advance of ice shelves (Nansen Ice Sheet and Hells Gate). This evidence is documented at Inexpressible Island and on the Cape Russell peninsula where the ice shelves directly face or cover Holocene raised beaches (BARONI and OROMBELLI, 1989, 1994b).

Additional information on environmental changes are documented by variations of local glaciers. An important withdrawal phase of the Edmonson Point glacier occurred during the *Medieval Warm Period* (XI-XIII Centuries A.D.). This retreat was followed by a phase of expansion during the *Little Ice Age* (BARONI and OROMBELLI, 1994b).

The diffuse finding of abandoned Adélie penguin rookeries supplies new information on the Holocene environmental picture (BARONI and OROMBELLI, 1994a). The highest concentration of abandoned rookeries was found between Wood Bay and McMurdo Sound. This section of coast has recorded higher environmental variability, particularly regarding the factors that regulate the presence of penguins. One of these factors, probably the most important, is the variation of the extent and of the persistence of fast ice.

The largest number of fossil rookeries occurred between 5 and 4 kyr B.P. a period that we propose to define as the "penguin optimum" (BARONI and OROMBELLI, 1994a). A sudden decrease in the number of rookeries occurred sometime shortly after 4 kyr B.P. This decrease is considered to be related to some brusque change in environmental conditions.

Due to the abundance and spatial distribution of penguins in Antarctica, considerable environmental information can be gathered from penguin behaviour as a response to the variations of the sea-ice extent as well as to climatic conditions.

Acknowledgments

This work has been carried out in the framework of the Italian Antarctic Research Program and was financially supported by ENEA through a joint research program on Antarctic Earth Sciences with the University of Siena. I thank Prof. Yoshio YOSHIDA and Dr. Paul BERKMAN for their invitation to the workshop "Holocene environmental changes in Antarctic coastal areas" held in Tokyo October 20–22, 1993 and the National Institute of Polar Research (Japan) for its kind hospitality and support.

References

ANDERSON, J. B., DOMACK, E. W., KENNEDY, D. and SMITH, M. (1991): Sedimentary facies associated with Antarctica's floating ice masses. Paleoclimatic Interpretation from Glacial Marine Deposits, ed. by J. B. ANDERSON and G. M. ASHLEY. Boulder, Geological Society of America, 1–26 (Spec. Publ.).

ARÇTOWSKI, H. (1901): The Antarctic voyage of the "Belgica" during the years 1897, 1898, and 1899. Geogr. J., **18**, 353-394.

BARONI, C. (1989): Geomorphological map of the Northern Foothills near the Italian Station, (Terra Nova Bay, Antarctica). Mem. Soc. Geol. Ital., **33** (1987), 195–211.

BARONI, C. (1990): The Hells Gate and Backstairs Passage Ice Shelves, Victoria Land–Antarctica. Mem. Soc. Geol. Ital., **43**, 123–144.

BARONI, C. and OROMBELLI, G. (1989): Glacial geology and geomorphology of Terra Nova Bay (Antarctica). Mem. Soc. Geol. Ital., **33** (1987), 171–193.

BARONI, C. and OROMBELLI, G. (1991): Holocene raised beaches at Terra Nova Bay, Victoria Land, Antarctica. Quat. Res., **36**, 157–177.

BARONI, C. and OROMBELLI, G. (1994a): Abandoned penguin rookeries as Holocene palaeoclimatic indicators in Antarctica. Geology, 22, 23–26.

BARONI, C. and OROMBELLI, G. (1994b): Holocene glacier variations in the Terra Nova Bay area (Victoria Land, Antarctica). to be published in Antarct. Sci. (in press).

BARONI, C., BELLUOMINI, G., BRANCA, M. E., IMPROTA, S. and OROMBELLI, G. (1991): Radiocarbon dates from Terra Nova Bay (Northern Victoria Land, Antarctica), conventional and calibrated ages. Mem. Soc. Geol. Ital., **46**, 81–92.

BARSCH, D. and MÄUSBACHE, R. (1986): New data on the relief development of the South Shetland Islands, Antarctica. Interdisciplinary Sci. Rev., **11**, 211–219.

BARWICK, R. E. and BALHAM, R. W. (1967): Mummified seal carcasses in a deglaciated region of South Victoria Land, Antarctica. Tuatara, **15** (3), 165–180.

BJÖRK, S., HJORT, C., INGÓLFSSON, Ó. and SKOG G., (1991): Radiocarbon dates from the Antarctic Peninsula region-Problems and potential. Quat. Proc., **1**, 55–65.

CAMPBELL, I. B. and CLARIDGE, G. G. (1966a): Evidence of former sea levels near Cape Hallett, Antarctica. N. Z. J. Sci., **9**, 776–781.

CAMPBELL, I. B. and CLARIDGE, G. G. (1966b): A sequence of soils from a penguin rookery, Inexpressible Island, Antarctica. N. Z. J. Sci., **9**, 361–372.

CAMPBELL, I. B. and CLARIDGE, G. G. (1987): Antarctica: Soils, Weathering Processes and Environment. Amsterdam, Elsevier, 368 p.

CLAPPERTON, C.M. and SUGDEN, D. E. (1988): Holocene glacier fluctuations in South America and Antarctica. Quat. Sci. Rev., **7**, 185–198.

CLARIDGE, G. G. and CAMPBELL, I. B. (1966): The raised beaches at Inexpressible Island, Antarctica. N. Z. J. Sci., **9**, 889–900.

COLHOUN, E. A., MABIN, M. C. G., ADAMSON, D. A. and KIRK, R. M. (1992): Antarctic ice volume and contribution to sea-level fall at 20,000 yr BP from raised beaches. Nature, **358**, 316–319.

DAVID, T. W. E. and PRIESTLEY, R. E. (1914): Glaciology, Physiography, Stratigraphy and Tectonic Geology of South Victoria Land. Report of British Antarctic Expedition 1907–09, **1**, 319 p.

DAWSON, A. G. (1990): Ice Age Earth. London, Routledge, 293 p.

DEBENHAM, F. (1923): British Antarctic ("Terra Nova") Expedition 1910–13. Report on the maps and surveys. London, Harrison, 94 p.

DENTON, G. H., BORNS, H. W., GROSSWALD, M. G., STUIVER, M. and NICHOLS, R. L. (1975): Glacial history of the Ross Sea. Antarct. J. U.S., **10**, 160–164.

DENTON, G. H., BOCKHEIM, J. G., WILSON, S. C. and STUIVER, M. (1989): Late Wisconsin and early Holocene glacial history, inner Ross embayment, Antarctica. Quat. Res., **31**, 151–182.

DENTON, G. H., PRENTICE, M. L. and BURCKLE, L. H. (1991): Cainozoic history of the Antarctic ice sheet. The Geology of Antarctica, ed. by R. J. TINGEY. Oxford, Oxford University Press, 365–433.

DREWRY, D. J. (1979): Late Wisconsin reconstruction for the Ross sea region, Antarctica. J. Glaciol., **24**, 231–244.

GOODWIN, I. D. (1993): Holocene deglaciation, sea-level change, and the emergence of the Windmill Islands, Budd Coast, Antarctica. Quat. Res., **40**, 70–80.

GREGORY, M. R., KIRK, R. M., and MABIN, M. C. (1984): Shore types of Victoria Land, Ross Dependency, Antarctica. N. Z. Antarct. Rec., **5**, 23–40.

HARRINGTON, H. J. (1960): Adélie penguin rookeries in the Ross Sea region. Notornis, **9** (2), 33–39.

HARRINGTON, H. J. and MCGELLAR, I. C. (1958): A radiocarbon date for penguin colonization of Cape Hallett, Antarctica. N. Z. J. Geol. Geophys., **1**, 571–576.

HEINE, J. C. and SPEIR, T. W. (1989): Ornithogenic soils of the Cape Bird Adélie penguin rookeries, Antarctica. Polar Biol., **10**, 89–99.

HERBERT, D. (1989): Kohlenstoff-14-Datierung antarktischer Pinguinbruttstätten. Beit. Vogelkd., **26**, 335–341.

HILLER, A., WAND, U., KÄMPF, H. and STACKEBRANDT, W. (1988): Occupation of the Antarctic continent by petrels during the past 35,000 years: Inference from a ^{14}C study of stomach oil deposits. Polar Biol., **9**, 69–77.

KARL, H. A. (1989): High-resolution seismic reflection interpretations of some sediment deposits, Antarctic continental margin: focus on the western Ross Sea. Mar. Geol., **85**, 205–223.

KELLOGG, T. B., TRUESDALE, R. S. and OSTERMAN, L. E. (1979): Late Quaternary extent of the West antarctic ice sheet: new evidence from Ross Sea cores. Geology, **7**, 249–253.

KELLOGG, T. B., KELLOGG, D. E. and STUIVER, M. (1990): Late Quaternary history of the southwestern Ross Sea: evidence from debris bands on the McMurdo Ice Shelf, Antarctica. Contributions to Antarctic Research I, ed. by C.R. Bentley. Washington, D.C., Am. Geophys. Union, 24–56 (Antarctic Research Series, Vol. 50).

KIRK, R. M. (1991): Raised beaches, late Quaternary sea-levels and deglacial sequences on the Victoria

Land coast, Ross Sea, Antarctica. GILLIESON, D. and FITZSIMONS, S., Eds., Quaternary Research in Australian Antarctica: Future directions. Special Publication No. 3, Department of Geography and Oceanography, University College, Australian Defence Force Academy, Canberra, 85–105.

KRISSEK, L. A. (1988): Sedimentation history of the Terra Nova Bay region, Ross Sea, Antarctica. Antarct. J., **23** (5), 104–105.

MABIN, M. C. G. (1985): ^{14}C ages for "Heroic Era" penguin and seal bones from Inexpressible Island, Terra Nova Bay, North Victoria Land. N. Z. Antarct. Rec., **6** (2), 24–25.

MABIN, M. C. G. (1986a): ^{14}C ages for "Heroic Era" penguin and seal remains from Cape Evans, McMurdo Sound. N. Z. Antarct. Rec., **7** (2), 19–20.

MABIN, M. C. G. (1986b): The Ross Sea section of the Antarctic ice sheet at 18000 yr B.P.: Evidence from Holocene sea-level changes along the Victoria Land coast. S. Af. J. Sci., **82**, 506–508.

NICHOLS, R. L. (1966): Geomorphology of Antarctica. Antarctic Soils and Soil Forming Processes, ed. by J. C. F. TEDROW. Washington, D.C., Am. Geophys. Union, 1–46 (Antarctic Research Series, Vol. 8).

NICHOLS, R. L. (1968): Coastal geomorphology, McMurdo Sound, Antarctica. J. Glaciol., **7**, 449–478.

OMOTO, K. (1983): The problem and significance of radiocarbon geochronology in Antarctica. Antarctic Earth Science, ed. by R. L. OLIVER *et al.* Cambridge, Cambridge, University Press, 450–452.

OROMBELLI, G. (1986): La prima spedizione del Programma Nazionale di Ricerche in Antartide. Osservazioni geomorfologiche. Riv. Geogr. Ital., **93** (2), 129–169.

OROMBELLI, G. (1988): Le spiagge emerse oloceniche della Baia Terra Nova (Terra Vittoria, Antartide). Atti Accad. Naz. Lincei, s. VIII, **81** (4, 1987), 403–416.

OROMBELLI, G. and PORTER, S. C. (1983): Lichen growth curves for the southern flank of the Mont Blanc Massif, Western Italian Alps. Arct. Alp. Res., **15**, 207–237.

OROMBELLI, G., BARONI, C. and DENTON, G. H. (1991): Late Cenozoic glacial history of the Terra Nova Bay region, Northern Victoria Land, Antarctica. Geogr. Fis. Din. Quat., **13** (1990), 139–163.

PRIESTLEY, R. E. (1923): Physiography (Robertson Bay and Terra Nova Bay regions). British Antarctic ("Terra Nova") Expedition 1910–13. London, Harrison, 95 p.

REID, D. E. (1989): Quaternary marine geology of the northwestern Ross Sea. Antarct. J. U. S., **24** (5), 128–130.

SCOTT, R. F. (1905): The Voyage of the Discovery. London, John Murray, 720 p.

SPEIR, T. W. and COWLING, J. C. (1984): Ornithogenic soils of the Cape Bird Adélie penguin rookeries, Antarctica. 1. Chemical properties. Polar Biol., **2**, 199–205.

SPELLERBERG, I. F. (1970): Abandoned penguin rookeries near Cape Royds, Ross Island, Antarctica and ^{14}C dating of penguin remains. N.Z. J. Sci., **13**, 380–385.

STONEHOUSE, B. (1970): Recent climatic changes in Antarctica suggested from ^{14}C dating of penguin remains. Palaeogeogr., Palaeoclimatol. Palaeoecol., **7**, 341–343.

STUIVER, M. and BRAZIUNAS, T. F. (1985): Compilation of isotopic dates from Antarctica. Radiocarbon, **27** (2a), 304 p.

STUIVER, M. and BRAZIUNAS, T. F. (1993): Modelling atmospheric ^{14}C influences and ^{14}C ages of marine samples to 10000 BC. Radiocarbon, **35** (1), 137–189.

STUIVER, M. and REIMER, P. J. (1993): Extended ^{14}C data base and revised CALIB 3.0 ^{14}C age calibration program. Radiocarbon, **35** (1), 215–230.

STUIVER, M., DENTON, G. H., HUGHES, T. and FASTOOK, J. L. (1981): History of the Marine Ice Sheet in West Antarctica during the last glaciation: a working hypothesis. The Last Great Ice Sheets, ed. by G. H. DENTON and T. HUGHES. New York, Wiley, 319–369.

STUIVER, M., PEARSON, G. W. and BRAZIUNAS, T. F. (1986): Radiocarbon age calibration of marine samples back to 9000 cal yr B.P. Radiocarbon, **28** (2b), 980–1021.

SYROECHKOVSKY, E. E. (1959): The role of animals in the formation of primary soils under the conditions of circumpolar regions of the earth (Antarctica). Zool. Zh. Ukr., **38**, 1770–1775.

TAVIANI, M., Reid, D. E. and ANDERSON, J. B. (1993): Skeletal and isotopic composition and paleoclimatic significance of Late Pleistocene carbonates, Ross Sea, Antarctica. J. Sediment. Petrol., **63** (1), 84–90.

TAYLOR, T. G. (1922): The Physiography of the McMurdo Sound and Granite Harbour Region. British Antarctic ("Terra Nova") Expedition 1910–13. London, Harrison, 246 p.

TEDROW, J. C. F. and UGOLINI, F. C. (1966): Antarctic soils. Antarctic Soils and Soil Forming Processes, ed. by J. C. F. TEDROW. Washington, D.C., Am. Geophys. Union, 161–177 (Antarctic Research Series, Vol. 8).

UGOLINI, F. C. (1972): Ornithogenic soils of Antarctica. Antarctic Terrestrial Biology, ed. by G.A. LLANO. Washington, D.C., Am. Geophys. Res., 181–193 (Antarctic Research Series, Vol. 20).

WHITEHOUSE, I. E., CHINN, T. J. and HÖFLE, H. C. (1988). Radiocarbon contaminated penguin bones from Terra Nova Bay, Antarctica. N. Z. Antarct. Rec., **8** (3), 11–23.

WHITEHOUSE, I. E., CHINN, T. J. and HÖFLE, H. C. (1989): Radiocarbon dates from raised beaches, Terra Nova Bay, Antarctica. Geol. Jahrb., Reihe, E**38**, 331–334.

(Received January 24, 1994; Revised manuscript received May 14, 1994)

Appendix 7. Inventory of ornithogenic soils (Fig. 7).

A—Inexpressible Island, "Snow Cave Site" Bay (74°54′21″S–163°43′42″E–20.7 m a.s.l.).
0–5 cm: subrounded pebbles with lichen cover; lineary clear boundary.
5–9 cm: greyish brown (2.5 Y 5/2) gravelly fine sand with organic matter (eggs and few guano); moist, friable; sample GX-13613 (3010 ± 220 ^{14}C yr B.P.); lineary sharp boundary.
9–11.5 cm: dark reddish brown (5 YR 3/3, 2.5/2) gravelly guano with bones, eggs and feathers, very strong odour; moist, friable to firm; sample GX-13608 (5360 ± 90 ^{14}C yr B.P.); wavy clear boundary.
11.5–13 cm: yellowish red (5 YR 5/6) gravelly guano with many egg fragments, strong to very strong odour; moist, friable to firm; wavy sharp boundary.
13–25 cm: white (10 YR 8/2) pebbly sandy silt with guano; moist, friable to slightly firm; sample GX-13614 (5945 ± 340 ^{14}C yr B.P.); lineary clear boundary.
25–30 cm: light brownish gray (2.5 Y 6/2) bouldery sand; moist, friable; wavy clear boundary.
30–40 cm: brown (7.5 YR 5/4) bouldery organic silt (between boulders and at the bottom of them); moist, friable to slightly firm; sample GX-13615 (6335 ± 110 ^{14}C yr B.P.); linear clear boundary.
40–50 cm: bouldery sandy silt; friable, distinct boundary on frozen ground.

B—Inexpressible Island, "Snow Cave Site" Bay. (74°54′21″S–163°43′42″E–19.7 m a.s.l.).
0–5 cm: subrounded pebbles with lichen cover; lineary clear boundary.
5–12 cm: dark reddish brown (5 YR 3/3) bouldery to pebbly guano with bones, egg fragments and feathers, very strong odour; moist, friable to firm; sample GX-13610 (5440 ± 85 ^{14}C yr B.P.); wavy sharp boundary.
12–25 cm: white (10 YR 8/2) bouldery sandy silt with guano; moist, friable; sample GX-13611 (5530 ± 100 ^{14}C yr B.P.); lineary clear boundary.
25–30 cm: light brownish gray (2.5 Y 6/2) bouldery sand; moist, friable; linery clear boundary.
30–40 cm: brown (7.5 YR 5/4) boulders organic silt (between boulders and at the bottom of them); moist, friable to slightly firm; sample GX-13612 (6235 ± 110 ^{14}C yr B.P.); lineary clear boundary.
40–55 cm: bouldery sandy silt; distinct boundary on frozen ground.

C—Prior Island (75°41′33″S–162°52′38″E–18 m a.s.l.).
0–9 cm: very pale brown (10 YR 7/4) guano, strong odour; dry, laminated, soft; sample GX-16931 (1910 ± 75 ^{14}C yr B.P.); wavy clear boundary.
9–16 cm: light yellowish brown (10 YR 6/4) guano, strong odour; dry, medium blocky; hard; sample GX-16930 (2105 ± 75 ^{14}C yr B.P.); wavy sharp boundary.
16–28 cm: light yellowish brown (10 YR 6/4) guano with rare small rounded pebbles; strong odour; dry, loose to soft; sample GX-16929 (2205 ± 75 ^{14}C yr B.P.); wavy sharp boundary.
28–38 cm: brown (7,5 YR 4/4) guano with bones, egg fragments and feathers; very strong odour; moist, very sticky; sample GX-16928 (2385 ± 80 ^{14}C yr B.P.); wavy sharp boundary.
38 + cm: bedrock.

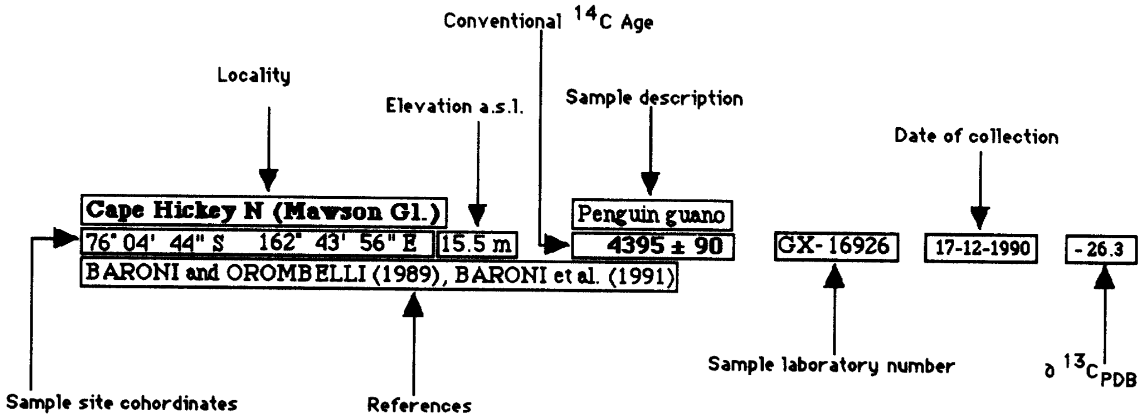
D—Mt. McGee (74°0′24″S–164°28′24″E–1110 m a.s.l.).
0–8 cm: very pale brown (10 YR 7/4) Snow Petrel stomachal oil; strong odour; moist, laminated, firm; AMS sample TO-2660 (5470 ± 80 ^{14}C yr BP); wavy sharp boundary.
8–18 cm: reddish brown (5 YR 4-3/4) guano and stomachal oil with bones and egg fragments; odour; moist, medium blocky, hard, locally cemented; AMS sample TO-2659 (9080 ± 100 ^{14}C yr BP); wavy sharp boundary.
18–30 cm: gray sandy gravel (angular) with pebbles; wavy sharp boundary.
30 + cm: bedrock.

E—Cape Hickey W, Mawson Glacier (76°05′08″S–162°38′19″E–40 m a.s.l.).
0–12 cm: angular to subangular pebbles with lichen cover; lineary clear boundary.
12–30 cm: brown (7,5 YR 4/4) guano between boulders and pebbles, odour; dry, very friable; wavy gradual boundary.

30–34 cm: brown (7,5 YR 4-5/4) guano with egg fragments; srong odour, dry, very friable; samples GX-16925 and GX-18483 (11325±360 and 13070±405 ^{14}C yr B.P.); wavy sharp boundary.
34–60 cm: gray sandy to gravelly boulders; moist, friable; wavy sharp boundary.
60+cm: bedrock.

Appendix 8. Inventory of radiocarbon dates from Antarctic penguin remains.

A list of 95 ^{14}C dates from Antarctic penguin remains is presented. Most of the dates (89) come from Victoria Land and only 6 from other Antactic regions. Abandoned and presently occupied rookeries fournish several ornithogenic soils suitable for ^{14}C dating. Numerical dates from organic samples in coastal areas are necessary for the reconstruction of deglaciation history, Holocene glacier fluctuations and relative sea-level curves. Penguins can be very useful to reach this targets.



Explanation of date list format

Most of the conventional ^{14}C ages supplied by BARONI and OROMBELLI were made by Krueger Enterprises Inc., Geochron Laboratories Division, in Cambridge, Massachusetts (the laboratory number is labelled with initial GX-); other conventional dates were supplied by the "Centro di Studio per la Cronologia e Geochimica delle Formazioni recenti, C.N.R.", Roma (the laboratory number is labelled with initial R-). The A.M.S. dates were made by Isotrace Radiocarbon Laboratory, Toronto, Canada (the laboratory number is labelled with initial TO-). All the conventional dates are based upon the ^{14}C Libby half life (5570 years). The A.M.S. dates are based on the ^{14}C Libby meanlife of 8033 years. The ages are referred to A.D. 1950. Other dates here listed were supplied by several authors.

Victoria Land .

Beaufort Island		Penguin bone			
76°58'S	167°53'E		1150±45	NZ-?	1959
HARRINGTON (1960)					
Cape Barne, Ross Island		Penguin remains			
77°34'S	166°14'E		116±51	NZ-?	1963, 1966
SPELLERBERG (1970)					
Cape Barne, Ross Island		Penguin remains			
77°34'S	166°14'E		179±103	NZ-?	1963, 1966
SPELLERBERG (1970)					
Cape Barne, Ross Island		Penguin remains			
77°34'S	166°14'E		274±45	NZ-?	1963, 1966
SPELLERBERG (1970)					
Cape Barne, Ross Island		Penguin remains			
77°34'S	166°14'E		374±57	(NZ)R-1488	Nov. 1964

STONEHOUSE (1970)						
Cape Bird, Ross Island			Penguin remains			
77°13'S	166°28'E	3 m	7070 ± 180	NZ-5590	1982	
SPEIR and COWLING (1984)						
Cape Bird, Ross Island			Penguin remains			
77°13'S	166°28'E	3 m	8080 ± 160	NZ-5990	1982	
HEINE and SPEIR (1989)						
Cape Day N, Oates Piedmont Glacier			Penguin guano			
76°14'44"S	162°47'26"E	18 m	4180 ± 90	GX-16923	17-12-1990	−26.5
BARONI and OROMBELLI (1994)						
Cape Day N, Oates Piedmont Glacier			Penguin guano			
76°14'44"S	162°47'26"E	17 m	4230 ± 85	GX-16910	17-12-1990	−26.2
BARONI and OROMBELLI (1994)						
Cape Evans, Ross Island			Emperor penguin bone collagen			
77°38'E	166°25'E	—	1105 ± 55	NZ-7079A	Nov. 1985	
MABIN (1986a)–Sample of known age, 1916 A.D.						
Cape Evans, Ross Island			Emperor penguin flesh and feathers			
77°38'S	166°25'E	—	1220 ± 55	NZ-7076A	Nov. 1985	
MABIN (1986a)–Sample of known age, 1916 A.D.						
Cape Hallett			Penguin guano			
72°19'S	170°12'E	few m	1210 ± 70	R-384	1958	
HARRINGTON and MCGELLAR (1958)						
Cape Hickey N (Mawson Gl.)			Penguin guano			
76°04'44"S	162°43'56"E	15.5 m	4365 ± 90	GX-16927	17-12-1990	−26.5
BARONI and OROMBELLI (1994)						
Cape Hickey N (Mawson Gl.)			Penguin guano			
76°04'44"S	162°43'56"E	15.5 m	4395 ± 90	GX-16926	17-12-1990	−26.3
BARONI and OROMBELLI (1994)						
Cape Hickey W (Mawson Gl.)			Penguin guano			
76°05'08"S	162°38'19"E	40 m	11325 ± 360	GX-16925	17-12-1990	−27.6
BARONI and OROMBELLI (1994)						
Cape Hickey W (Mawson Gl.)			Penguin guano			
76°05'08"S	162°38'19"E	40 m	13070 ± 405	GX-18483	17-12-1990	−28.2
BARONI and OROMBELLI (1994)						
Cape Ross, Scott Coast			Penguin guano			
76°43'59"S	162°59'45"E	29.2 m	4310 ± 155	GX-16918	27-12-1990	−27.3
BARONI and OROMBELLI (1994)						
Cape Ross, Scott Coast			Penguin guano			
76°43'56"S	162°59'25"E	28.1 m	4255 ± 155	GX-16920	27-12-1990	−27.2
BARONI and OROMBELLI (1994)						
Cape Ross, Scott Coast			Penguin guano			
76°43'59"S	162°59'50"E	31.7 m	4315 ± 90	GX-16911	30-12-1990	−27.3
BARONI and OROMBELLI (1994)						
Cape Ross, Scott Coast			Penguin guano			
76°43'59"S	162°59'50"E	31.2 m	4465 ± 90	GX-16912	30-12-1990	−27.2
BARONI and OROMBELLI (1994)						
Cape Ross, Scott Coast			Penguin guano			
76°43'55"S	162°59'25"E	24.5 m	4555 ± 90	GX-16921	27-12-1990	−25.3
BARONI and OROMBELLI (1994)						
Cape Ross, Scott Coast			Penguin guano			
76°44'07"S	163°00'E	27.5 m	4570 ± 90	GX-16913	29-12-1990	−26.2
BARONI and OROMBELLI (1994)						
Cape Ross, Scott Coast			Penguin guano			

76°43′56″S	163°00′35″E	31.5 m	4570±90	GX-16914	29-12-1990	−26.2
BARONI and OROMBELLI (1994)						
Cape Ross, Scott Coast			Penguin guano			
76°43′59″S	162°59′45″E	28.7 m	4735±165	GX-16919	27-12-1990	−26.3
BARONI and OROMBELLI (1994)						
Cape Ross, Scott Coast			Penguin gauno			
76°43′55″S	162°59′25″E	21 m	4780±160	GX-16922	27-12-1990	−25.8
BARONI and OROMBELLI (1994)						
Cape Royds			Adélie penguin flesh			
77°32′S	166°11′E		925±75	?-4432	1963, 1966	
WHITHOUSE *et al.* (1989)–Sample of known age, 1904 A.D.						
Cape Royds, Clear Lake (Ross Island)			Penguin remains			
77°32′S	166°11′E		600±100	NZ-?	1963, 1966	
SPELLERBERG (1970)						
Edmonson Point, Wood Bay			Penguin guano			
74°20′S	165°8′12″E	6 m	1650±70	GX-13601	26-12-1986	−26.7
BARONI *et al.* (1991)						
Edmonson Point, Wood Bay			Penguin guano			
74°19′45″S	164°5′E	40 m	2870±155	GX-14076	18-01-1988	−26.2
BARONI *et al.* (1991)						
Evans Cove, Cape Russell Peninsula			Penguin bones			
74°52′52″S	163°54′51″E		1805±235	GX-14072	02-01-1988	−21.5
BARONI *et al.* (1991)						
Fork S, Wright Valley			Adélie penguin flesh			
77°35′S	161°05′E		560±?	R.809/3	before 1967	
BARWICK and BALHAM (1967), STUIVER and BRAZIUNAS (1985)						
Franklin Island			Penguin remains			
76°05′S	168°19′E		1750±70	QL-170	before 1980	
STUIVER *et al.* (1981)						
Franklin Island			Penguin remains			
76°05′S	168°19′E		3150±80	QL-169	before 1980	
STUIVER *et al.* (1981)						
Franklin Island			Penguin remains			
76°05′S	168°19′E		5340±50	QL-141	before 1980	
STUIVER *et al.* (1981)						
Hells Gate			Penguin bones			
74°52′40″S	163°45′–46′E	14 m	2295±135	GX-14623	21-01-1988	−21.5
BARONI *et al.* (1991)						
Inexpressible Island			Adélie penguin bones & flesh			
74°54′S	163°43′E	28.4 m	1060±45	NZ-6842A	Jan. 1983	
WHITEHOUSE *et al.* (1989)–Sample of known age, 1912 A.D.						
Inexpressible Island			Emperor penguin bones			
74°54′S	163°43′E	—	1065±50	NZ-6339A	Jan. 1983	
MABIN (1985)–Sample of known age, 1912 A.D.						
Inexpressible Island			Emperor penguin remains			
74°54′S	163°39′E	—	1300±50	QL-173	before 1980	
STUIVER *et al.* (1981)–Sample of known age, 1912 A.D.						
Inexpressible Island			Penguin remains			
74°54′S	163°43′E	11 m	1610±43	NZ-6963A	1984	
WHITEHOUSE *et al.* (1989)						
Inexpressible Island			Penguin remains			
74°54′S	163°39′E	<30 m	1770±43	QL-172	before 1980	
STUIVER *et al.* (1981)						

Inexpressible Island			Penguin remains (bone, flesh and feathers)			
74°54′S	163°43′E	22.7 m	2530 ± 50	NZ-7037A	1984	
WHITEHOUSE *et al.* (1989)						
Inexpressible Island			Penguin guano			
74°54′33″S	163°42′55″E	40 m	2900 ± 90	GX-13607	06-01-1986	−26.3
BARONI and OROMBELLI (1989), BARONI *et al.* (1991)						
Inexpressible Island			Penguin guano			
74°54′21″S	163°43′42″E	20.7 m	3010 ± 220	GX-13613	07-01-1987	−24.0
BARONI and OROMBELLI (1989), BARONI *et al.* (1991)						
Inexpressible Island			Penguin gauno			
74°54′21″S	163°43′42″E	6.2 m	3340 ± 85	GX-13616	07-01-1987	−26.1
BARONI and OROMBELLI (1989), BARONI *et al.* (1991)						
Inexpressible Island			Penguin guano			
74°54′21″S	163°43′42″E	14 m	3675 ± 90	GX-13617	07-01-1987	−25.0
BARONI and OROMBELLI (1989), BARONI *et al.* (1991)						
Inexpressible Island			Penguin guano			
74°54′21″S	163°43′42″E	14 m	4190 ± 80	GX-12757	16-01-1986	−25.8
BARONI and OROMBELLI (1989), BARONI *et al.* (1991)						
Inexpressible Island			Penguin guano			
74°54′21″S	163°43′42″E	26 m	4930 ± 85	GX-12758	16-01-1986	−24.6
BARONI and OROMBELLI (1989), BARONI *et al.* (1991)						
Inexpressible Island			Penguin remains			
74°54′21″S	163°43′42″E	20.7 m	5315 ± 100	GX-13609	07-01-1987	−24.2
BARONI and OROMBELLI (1989), BARONI *et al.* (1991)						
Inexpressible Island			Penguin remains			
74°54′21″S	163°43′42″E	20.7 m	5360 ± 90	GX-13608	07-01-1987	−25.2
BARONI and OROMBELLI (1989), BARONI *et al.* (1991)						
Inexpressible Island			Penguin remains			
74°54′21″S	163°43′42″E	60 m	5385 ± 85	GX-12756	16-01-1986	−25.0
BARONI and OROMBELLI (1989), BARONI *et al.* (1991)						
Inexpressible Island			Penguin remains			
74°54′21″S	163°43′42″E	19.7 m	5440 ± 85	GX-13610	07-01-1987	−25.8
BARONI and OROMBELLI (1989), BARONI *et al.* (1991)						
Inexpressible Island			Penguin guano			
74°54′21″S	163°43′42″E	19.7 m	5530 ± 100	GX-13611	07-01-1987	−25.6
BARONI and OROMBELLI (1989), BARONI *et al.* (1991)						
Inexpressible Island			Penguin guano			
74°54′33″S	163°42′55″E	40 m	5575 ± 185	GX-13606	06-01-1987	−25.8
BARONI and OROMBELLI (1989), BARONI *et al.* (1991)						
Inexpressible Island			Penguin guano			
74°54′″21S	173°43′42″E	20.7 m	5945 ± 340	GX-13614	07-01-1987	−25.6
BARONI and OROMBELLI (1989), BARONI *et al.* (1991)						
Inexpressible Island			Penguin guano			
74°53′20″S	163°44′2″E	50 m	6225 ± 105	GX-13618	08-01-1987	−26.0
BARONI and OROMBELLI (1989), BARONI *et al.* (1991)						
Inexpressible Island			Penguin guano			
74°54′21″S	163°43′42″E	19.7 m	6235 ± 110	GX-13612	07-01-1987	−25.4
BARONI and OROMBELLI (1989), BARONI *et al.* (1991)						
Inexpressible Island			Penguin guano			
74°54′21″S	163°43′42″E	20.7 m	6335 ± 110	GX13615	07-01-1987	−25.9
BARONI and OROMBELLI (1989), BARONI *et al.* (1991)						
Marble Point, Scott Coast			Penguin guano			
77°25′57″S	163°50′49″E	23 m	3905 ± 145	GX-16924	20-12-1990	−24.0

BARONI and OROMBELLI (1994)						
Northern Foothills, Adélie Cove			Penguin bones			
74°45'59"S	164°1'3"E	90 m	980±220	GX-12747	09-01-1986	−21.6
BARONI and OROMBELLI (1989), BARONI *et al.* (1991)						
Northern Foothills, Adélie Cove			Penguin bones			
74°46'S	164°0'45"E	90 m	1030±95	GX-12749	09-01-1986	−23.5
BARONI and OROMBELLI (1989), BARONI *et al.* (1991)						
Northern Foothills, Adélie Cove			Penguin guano (10 cm depth)			
74°46'1"S	164°0'3"E	75 m	1410±70	GX-13602	28-12-1986	−27.7
BARONI and OROMBELLI (1989), BARONI *et al.* (1991)						
Northern Foothills, Adélie Cove			Penguin guano			
74°46'S	163°59'E	5 m	1480±175	GX-15492	22-01-1989	−25.2
BARONI and OROMBELLI (1994)						
Northern Foothills, Adélie Cove			Penguin bones			
74°45'59"S	164°1'31"E	90 m	1560±290	GX-12748	09-01-1986	−23.1
BARONI and OROMBELLI (1989), BARONI *et al.* (1991)						
Northern Foothills, Adélie Cove			Penguin guano			
74°46'S	163°59'E	5 m	1687±175	GX-15491	22-01-1989	−26.7
BARONI and OROMBELLI (1994)						
Northern Foothills, Adélie Cove			Penguin bone			
74°46'S	164°E	5.8 m	1782±76	NZ-6919A	1984	
WHITEHOUSE *et al.* (1989)						
Northern Foothills, Adélie Cove			Penguin bone			
74°46'S	164°E	7.85 m	1857±68	NZ-6920A	1984	
WHITEHOUSE *et al.* (1989)						
Northern Foothills, Adélie Cove			Penguin guano			
74°46'S	164°0'42"E	90 m	2015±75	GX-12750		−28.4
BARONI and OROMBELLI (1989), BARONI *et al.* (1991)						
Northern Foothills, Adélie Cove			Penguin bone			
74°46'S	164°E	4.15 m	2420±80	NZ-6997A	1984	
WHITEHOUSE *et al.* (1989)						
Nothern Foothills, Adélie Cove			Penguin bone			
74°46'S	164°E	7.95 m	2780±45	NZ-7035A	1984	
WHITEHOUSE *et al.* (1989)						
Northern Foothills, Adélie Cove			Penguin bone			
74°46'S	164°E	4 m	4490±280	NZ-6906A	1984	
WHITEHOUSE *et al.* (1989)						
Northern Foothills, Gonwana Station			Penguin guano			
74°38'16"S	164°12'54"E	15 m	4615±85	GX-13620	19-01-1987	−24.6
BARONI and OROMBELLI (1989)						
Northern Foothills, Icarus Camp			Penguin remains			
74°42'43"S	164°7'6"E	40 m	4290±50	GX-12754	13-01-1986	−26.8
BARONI and OROMBELLI (1989)						
Northern Foothills, Icarus Camp			Penguin bones			
74°42'42"S	164°7'6"E	25 m	4495±135	GX-12755	13-01-1986	−20.7
BARONI and OROMBELLI (1989), BARONI *et al.* (1991)						
Northern Foothills, Icarus Camp			Penguin guano			
74°42'43"S	164°7'6"E	50 m	4495±95	GX-13619	19-01-1987	−24.8
BARONI and OROMBELLI (1989), BARONI *et al.* (1991)						
Northern Foothills, N Adélie Cove			Penguin guano			
74°44'8"S	164°6'22"E	52 m	6855±195	GX-13621	20-01-1987	−24.6
BARONI and OROMBELLI (1989), BARONI *et al.* (1991)						
Northern Foothills, N Adélie Cove			Penguin guano			

74°44′11″S	164°6′57″E	38.8 m	6860 ± 110	GX-13622	20-01-1987	−25.2
Baroni *et al.* (1991), Baroni and Orombelli (1994)						
Northern Foothills, N Adélie Cove			Penguin gauno			
74°44′11″S	164°6′57″E	38.8 m	7065 ± 250	GX-14098	11-02-1988	−27.1
Baroni (1989), Baroni and Orombelli (1989)						
Northern Foothills, Terra Nova Bay			Penguin guano			
74°41′40″S	164°6′56″E	19 m	4585 ± 105	GX-15494	04-02-1989	−24.5
Baroni and Orombelli (1994)						
Northern Foothills, Terra Nova Bay			Penguin guano			
74°41′40″S	164°6′56″E	18 m	4915 ± 115	GX-15495	04-02-1989	−23.9
Baroni and Orombelli (1994)						
Northern Foothills, Terra Nova Bay			Penguin guano			
74°41′40″S	164°6′56″E	18 m	5770 ± 60	GX-12760	09-02-1986	−29.4
Baroni and Orombelli (1989)						
Peninsula c/o Depot Island			Penguin guano			
76°42′03″S	162°57′E	16.3 m	3825 ± 150	GX-16915	28-12-1990	−28.8
Baroni and Orombelli (1994)						
Peninsula c/o Depot Island			Penguin guano			
76°42′09″S	162°56′09″E	22 m	3990 ± 100	GX-16916	28-12-1990	−27.7
Baroni and Orombelli (1994)						
Peninsula c/o Depot Island			Penguin guano			
76°41′57″S	162°56′44″E	52 m	4580 ± 100	GX-16917	28-12-1990	−27.4
Baroni and Orombelli (1994)						
Prior Island			Penguin guano			
75°41′33″S	162°52′38″E	17 m	1845 ± 75	GX-16933	17-12-1990	−26.2
Baroni and Orombelli (1994)						
Prior Island			Penguin guano			
75°41′33″S	162°52′38″E	17 m	1860 ± 75	GX-16932	17-12-1990	−26.7
Baroni and Orombelli (1994)						
Prior Island			Penguin guano			
75°41′33″S	162°52′38″E	18 m	1910 ± 75	GX-16931	17-12-1990	−25.4
Baroni and Orombelli (1994)						
Prior Island			Penguin guano			
75°41′33″S	162°52′38″E	18 m	2105 ± 75	GX-16930	17-12-1990	−26.2
Baroni and Orombelli (1994)						
Prior Island			Penguin guano			
75°41′33″S	162°52′38″E	18 m	2205 ± 75	GX-16929	17-12-1990	−25.8
Baroni and Orombelli (1994)						
Prior Island			Penguin guano			
75°41′33″S	162°52′38″E	18 m	2385 ± 80	GX-16928	17-12-1990	−27.6
Baroni and Orombelli (1994)						
Other Antarctic localities						
Bailey Penins., Budd Coast			Adélie penguin skull			
66°16′S	110°33′E		4380 ± 250	ANU-6403	1985-88	
Goodwin (1993)						
Hope Bay, Antarctic Peninsula			Penguin bones			
63°24′S	57°00′W		1280 ± 50	Lu-3101	1988	−21.7
Björck *et al.* (1991)–Sample of known age (Nordenskjöld Exp., 1903 A.D.)						
King George Is., South Shetland Is.			Penguin bone			
		18 m	6500 ± 90	HD 9425-100	before 1986	
Barsch and Mausbache (1986) cited by Clapperton and Sugden (1988)						
King Georg Is., South Shetland Is.			Penguin bone			

		18 m	6560 ± 55	HD 8426-106	before 1986	
BARSCH and MAUSBACHE (1986) cited by CLAPPERTON and SUGDEN (1988)						
Molodezhnaya, Enderby Land			Penguin guano			
67°40′S	45°50′E		1500 ± 500	—?	before 1980	
HERBERT (1980), STUIVER and BRAZIUNAS (1985)						
Shirmacher Oasis, Queen Maud Land			Egg (without shell) of Adélie penguin			
70°45′S	11°35′E	—	940 ± 80	—	before 1988	−29.7
HILLER *et al.* (1988)						